

Ozone variability and tendencies in the upper troposphere and lower stratosphere based on Aura MLS and sonde data



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UTLS ozone at low latitudes

- Changes in upper tropospheric and lower stratospheric (UTLS) O₃ at low lats. are closely connected to circulation changes, vertical changes in particular
 - > quasi-biennial oscillation (QBO) has a large impact on interannual change
 - > long O₃ lifetime, not much reactive chlorine; expect small impact from chemistry
 - > Long-term expectations/model results (*WMO, 2014*):
 - GHG increases → enhanced tropical upwelling → decreasing O₃ values
- In UTLS, difficult measurements (strong vertical gradients, low O₃, and high variability)
- Past work on O₃ trends in this region (*Randel and Thompson, 2011; Eckert et al., 2012; Kyrola et al., 2013; Gebhardt et al., 2014; Sioris et al., 2014; Bourassa et al., 2014*) indicates that “continued ozone decreases are not detected in the presence of large natural variability during 2002-2013” (*WMO, 2014*)
 - is there a hiatus in the expected long-term decrease in tropical O₃ (*Aschmann et al., 2014*)?
 - this may be coupled to lower sea surface temperatures
- Here, we examine version 4 O₃ data from Aura MLS (launched in July 2004) and compare this to ozonesonde profile data at low latitudes
 - > use Southern Hemisphere Additional Ozonesondes (SHADOZ) data (*Thompson et al., 2007*)

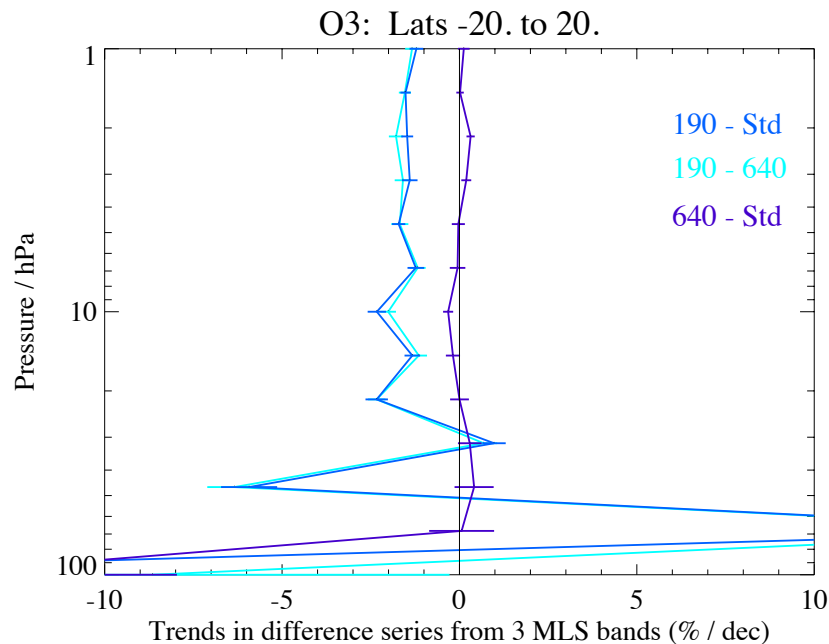
Temporal Stability of MLS Ozone Profiles

- Analyses have shown that MLS O₃ values are very stable with respect to ground-based profiles (*Nair et al.*, 2012; *Hubert et al.*, 2016); typically, MLS strat. O₃ stability < 2%/decade.
- We investigate MLS O₃ time series from different radiometers/bands.
 - most of the variability cancels out in difference series, and we obtain linear trends in diffs.

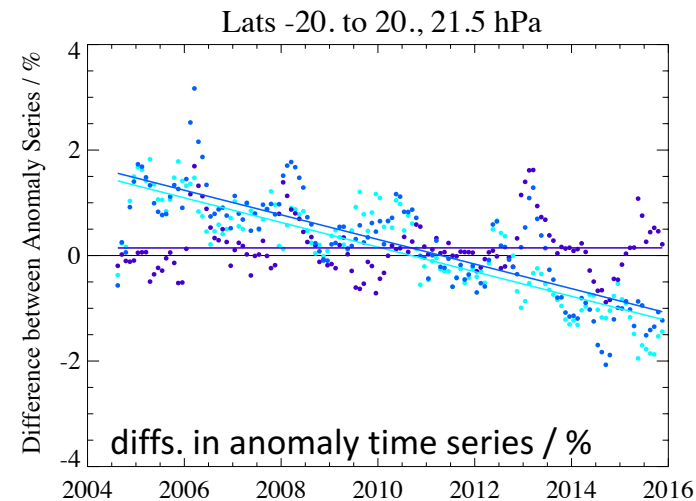
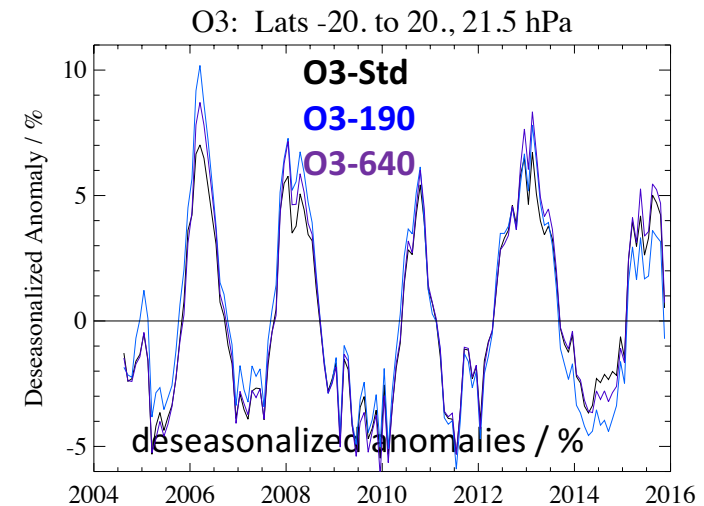
O3-Std: Ozone Standard Product from 240 GHz radiometer

O3-190: Ozone Product from 190 GHz radiometer (also for H₂O)

O3-640: Ozone Product from 640 GHz radiometer



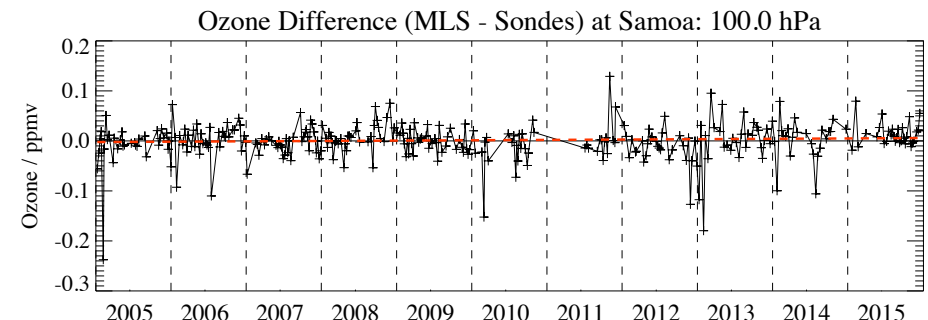
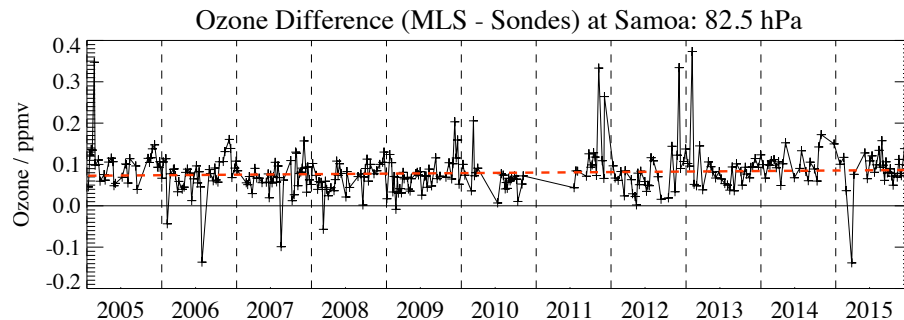
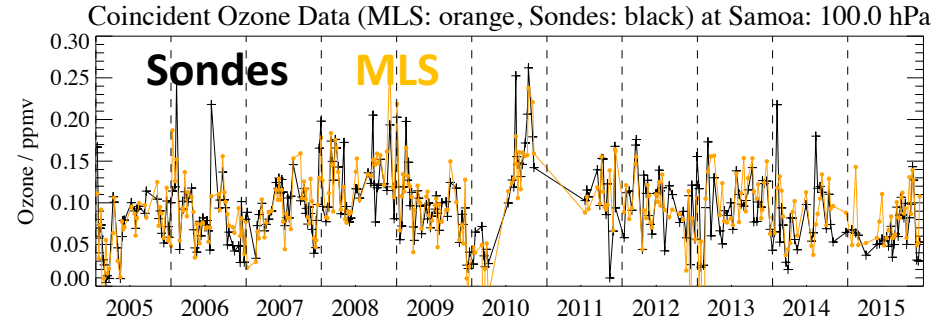
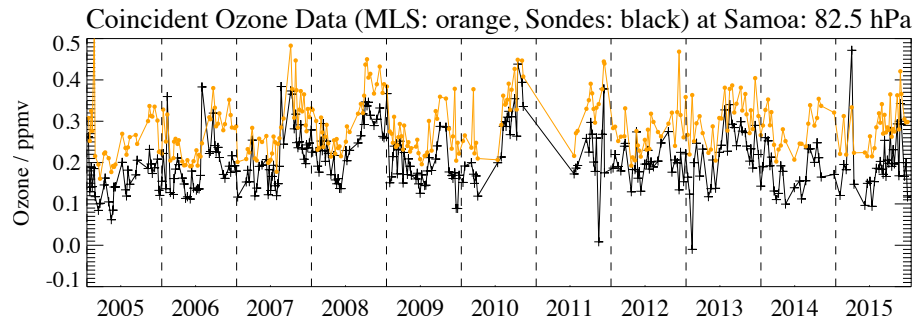
MLS v4 Ozone Data



- O3-190 differs the most from the other 2 ozone bands.**
- O3-Std & O3-640 are stable to < 1 %/dec from 1 to 70 hPa.**
- Similar (or better) results at mid-latitudes - not shown here.**

Coincident O₃ from Tropical Aura MLS and Sonde Profiles (2005-2015)

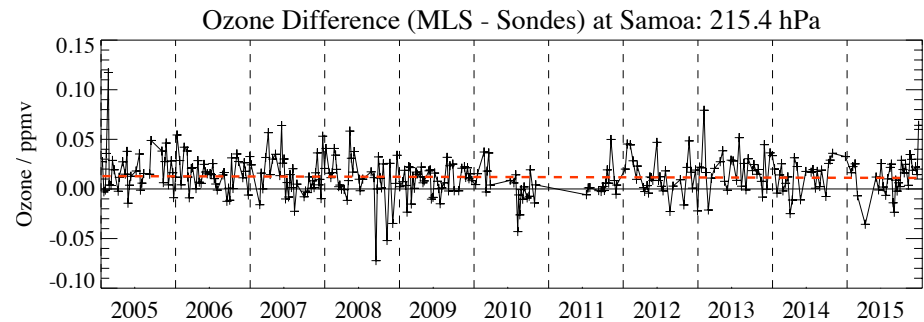
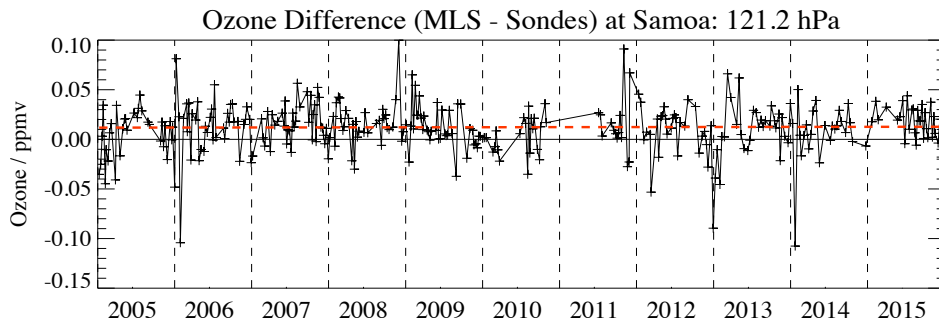
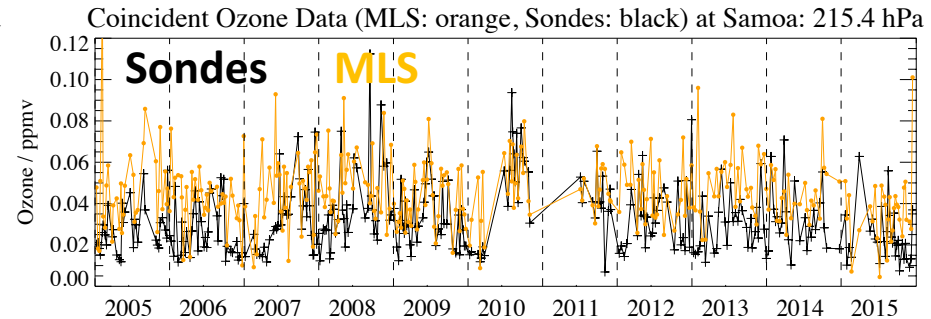
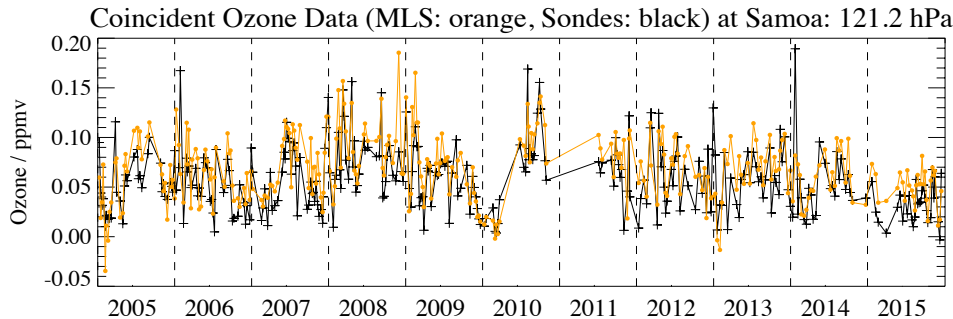
Sample Time Series for Samoa site: 82 hPa and 100 hPa



- Pick a few coincident MLS profiles, and get average MLS profile for each sonde profile
- Coincidence criteria: within $\pm 2^\circ$ latitude and $\pm 15^\circ$ longitude.
- Sonde profiles (x_{sonde}) are smoothed using averaging Kernels A_{MLS} (& a priori values x_a) from MLS: $x_{\text{sonde}}(\text{smooth}) = x_a + A_{\text{MLS}}(x_{\text{sonde}} - x_a)$ (Rodgers and Connor, 2003).
- We calculate average differences and simple linear trends/drifts (MLS – Sondes) (red dashed lines above) from the difference series.

Coincident O₃ from Tropical Aura MLS and Sonde Profiles (2005-2015)

Sample Time Series for Samoa site: 121 hPa and 215 hPa

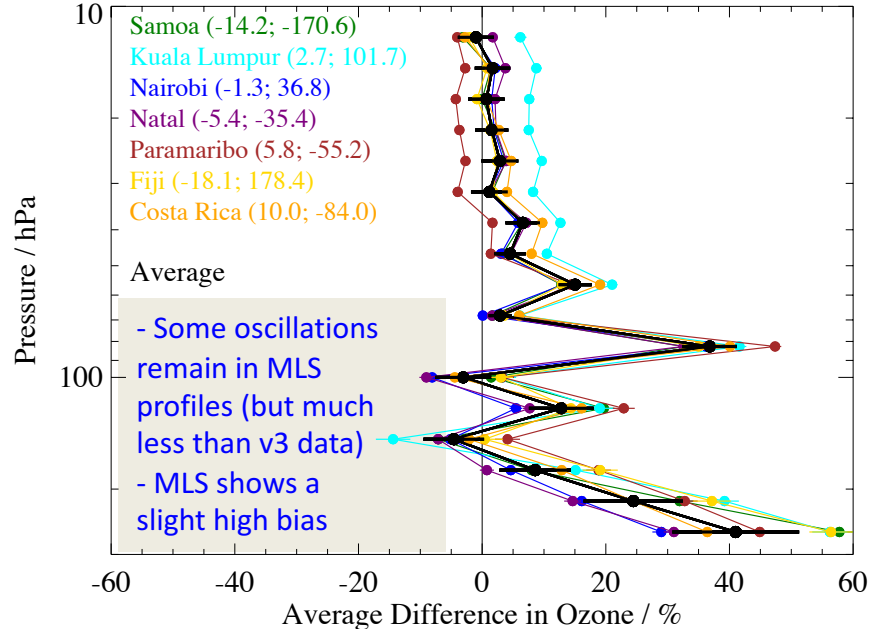


- We use **7 low latitude SHADOZ sites** with sufficient launches over the time period.
 - one to several sonde launches per week on average (2005 through 2015)
 - Samoa, Kuala Lumpur, Nairobi, Natal, Paramaribo, Fiji, Costa Rica*Credit/thanks to all the investigators who provided these public datasets.*
- We obtain average differences and trends of differences.

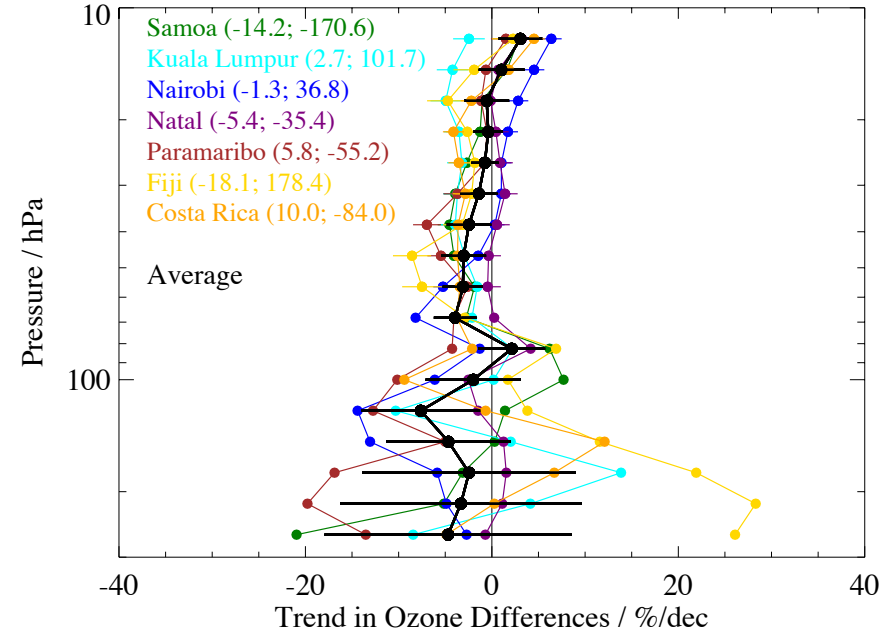
Coincident O₃ from Tropical Aura MLS and Sonde Profiles (2005-2015)

Average Differences (Biases) and Drifts from 7 ozonesonde sites

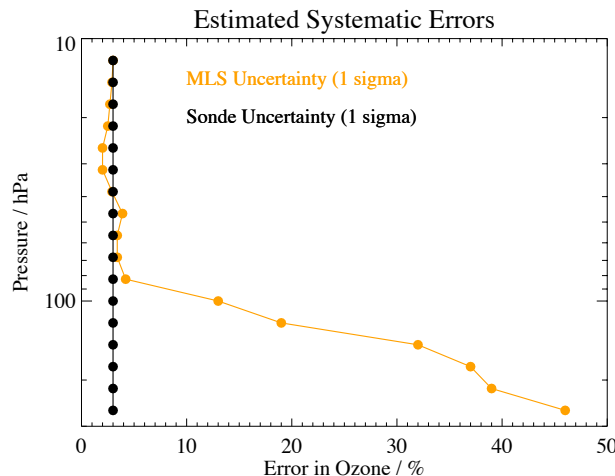
Average Diff. (MLS - Sonde): 7 sites at low latitudes



Drift (MLS - Sonde): 7 sites at low latitudes



Error bars in avg. results above: twice the standard error (based on the scatter in the 7 site results)



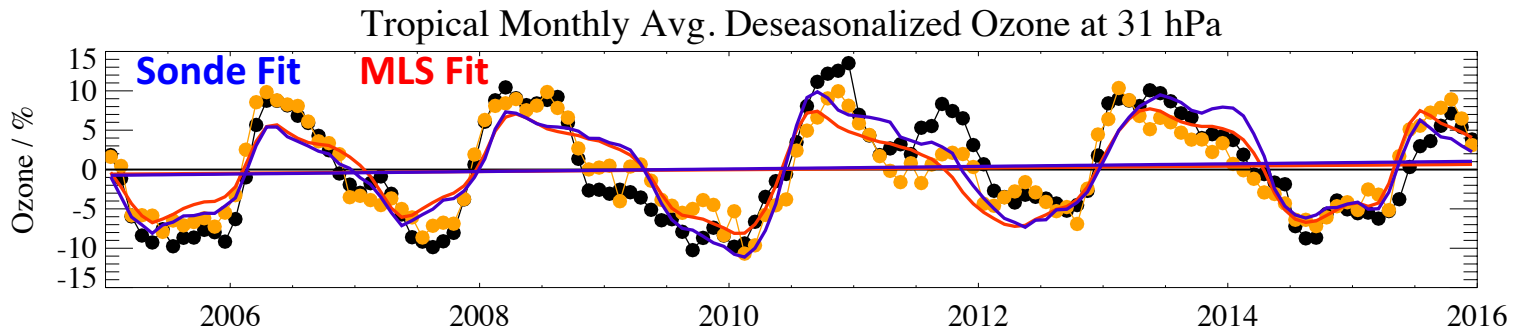
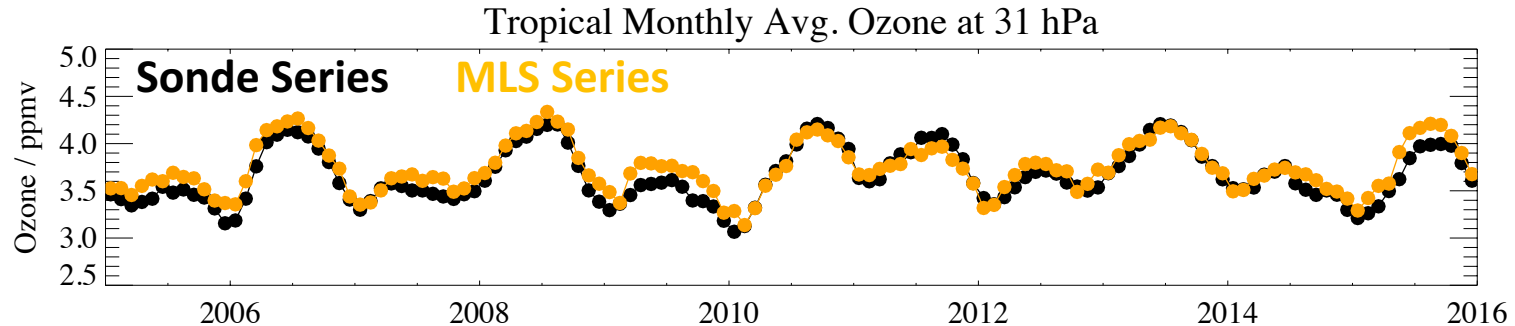
Systematic uncertainties

- Estimates for MLS are based on retrieval sensitivity tests
- For sondes, use 3% at all pressures (for simplicity)

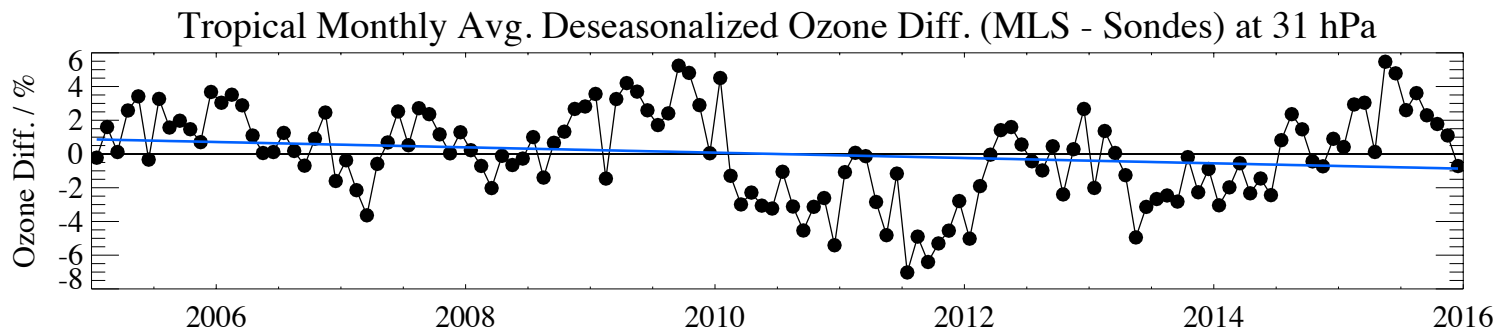
- MLS trends tend to be slightly < avg. sonde trends (by a few %/decade) but site-to-site variability is large.
- Typical drifts are consistent with zero drift.

Tropical Monthly Mean O₃: MLS versus Sondes

- Average the datasets from the 7 sites into monthly averages
- Use Multiple Linear Regression (MLR) to fit the deseasonalized time series

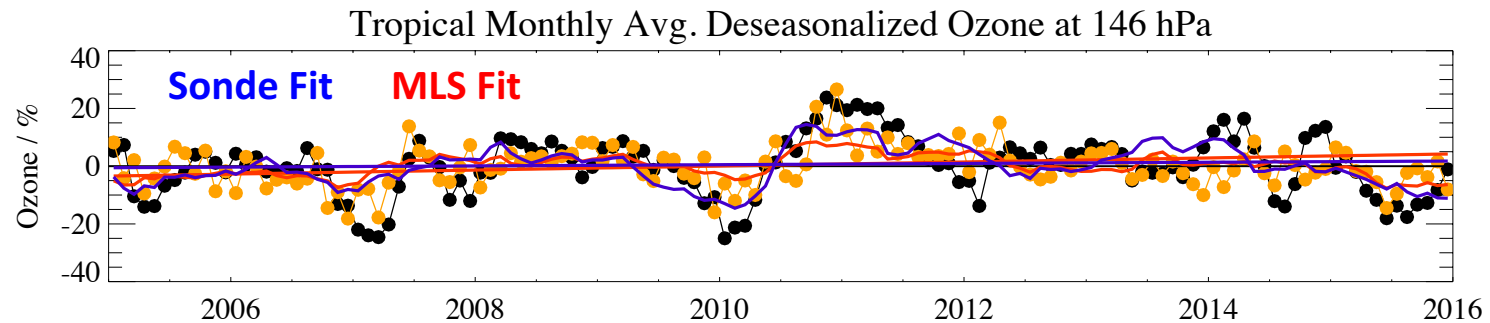
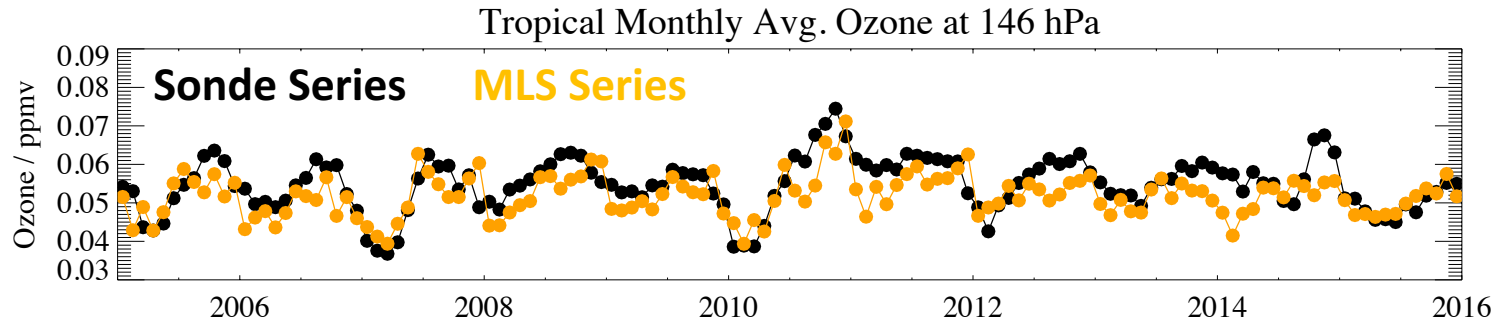


We obtain linear fits to the difference of the deseasonalized series

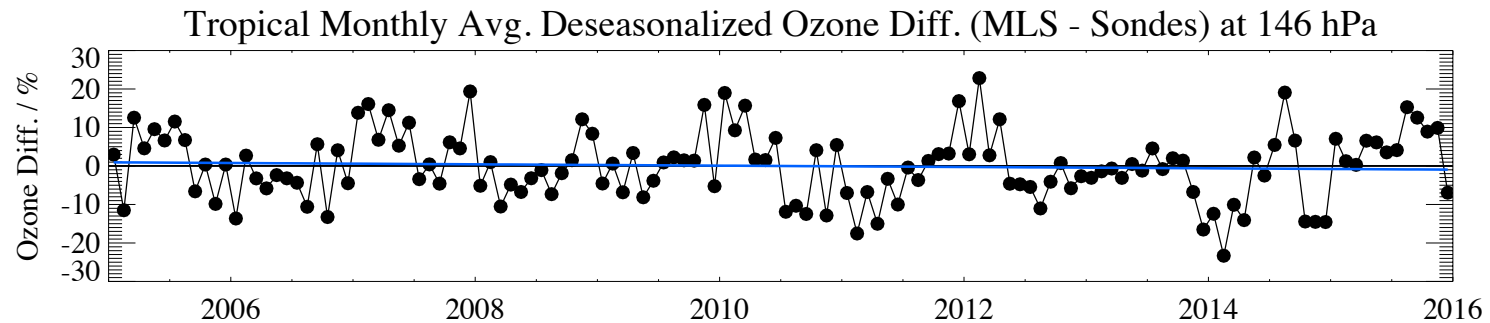


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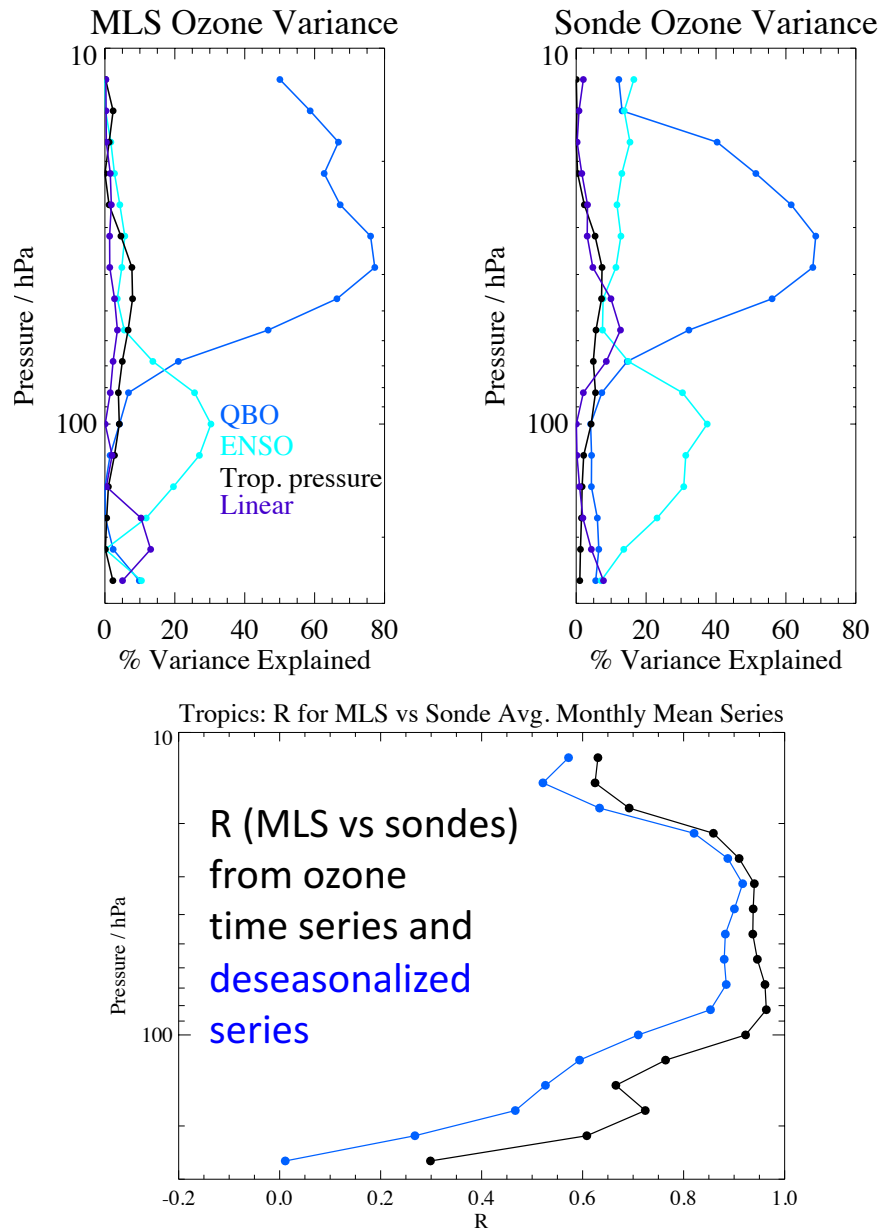
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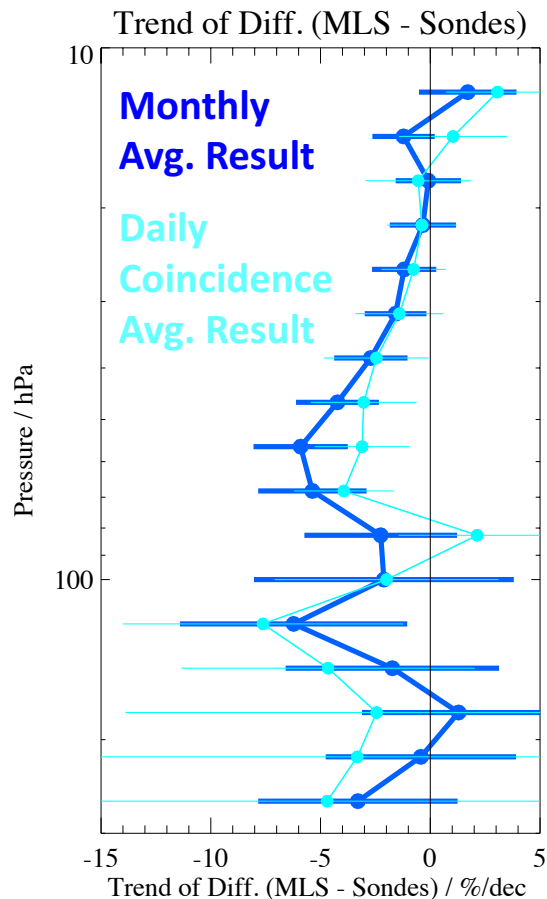
Regression fits and explained variance



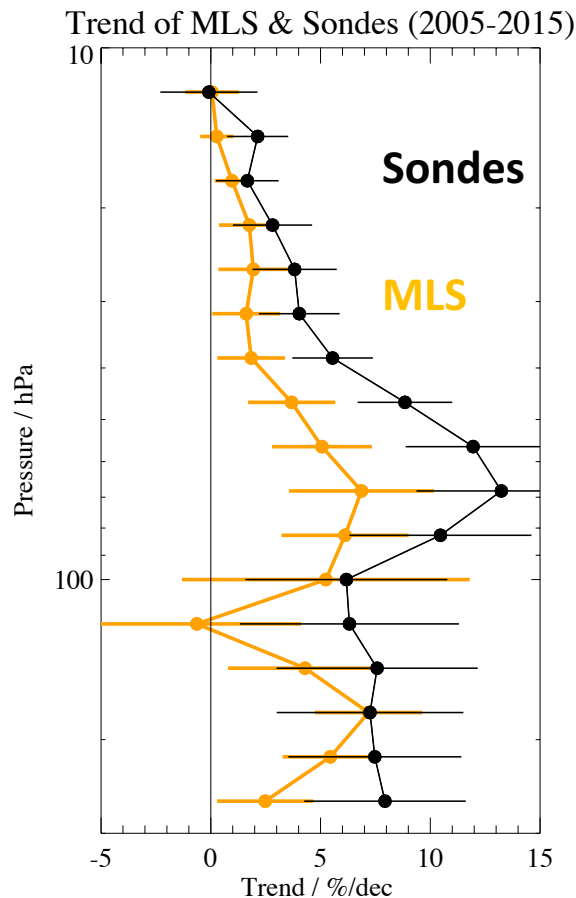
- **MLR fits include the following terms**
 - Constant and Linear Trend terms
 - QBO terms (from 30 hPa & 50 hPa winds)
> from Freie Universität Berlin, Inst. of Meteor.
 - Multivariate El Nino-Southern Oscillation (ENSO) index (MEI)
> from NOAA CDC (*Wolter, 2013*)
 - Tropopause pressure term
> from NCEP Reanalysis (*Kalnay et al., 1996*)
 - Solar cycle term was also tried
(but too correlated with linear term)
- **Explained Variance**
is shown at (top) left; the QBO and ENSO terms dominate (with a fair amount of unexplained variance in the UT).
> see also *Randel & Thompson (2011)*, *Oman et al. (2013)*, other past work, regarding impacts from QBO & ENSO
- **MLS and sondes agree well on the explained variance from fitted variables**

Ozone Trends and Drifts (2005-2015) at Low Latitudes

Drifts: MLS - Sonde Avg.



Trends: MLS and Sonde Data



- UTLS tropical ozone trends (2005-2015) are on the positive side ($\sim 5\%/decade$) for both **MLS** and avg. **sonde** data.
 - Results are similar (within error bars) to the results from *Gebhardt et al.* (2014) for 2002-2012.
- There is a small negative drift for MLS vs sonde avg. from both **monthly** and **coincident** avg. results.
- However, these results are generally not significant (except near 50 hPa).

Consistent with no continued decrease in 2005-2015.

How significant is the increasing trend? How “long-term”? Attribution?

Summary

- We have investigated **ozone in the tropical UTLS** based on 2005-2015 Aura MLS v4 and SHADOZ sonde data (Samoa, Kuala Lumpur, Nairobi, Natal, Paramaribo, Fiji, Costa Rica).
- **O₃ variability** arises mainly from QBO ($p < 70$ hPa) and ENSO ($p > 70$ hPa) components.
- Based on averaged results from these 7 tropical ozonesonde sites:
 - MLS is unbiased vs sondes from 10 to 30 hPa, but shows a positive bias (0 to 40%) in the UT and near the tropopause. Some MLS vertical oscillations remain at low lats/alts.
 - **Typical drifts are consistent with zero drift** (except near 50 hPa) but tend to be negative by a few %/decade (MLS gives smaller trends).
 - Monthly averages and coincidence averages give similar results.
 - MLS and sondes show trends of ~ 2 to 10%/decade, with 2σ errors of 3 to 7%/decade.
 - > this may not be a (real) long-term trend, but rather, a tendency for this past decade.
 - > results are in agreement with a hiatus in the (expected) long-term decrease.
- Unambiguous detection of a long-term trend of $< 2\%$ /decade will remain challenging.
 - having more years of data will allow for some refinements, assuming the same stability.
 - we also plan to update the GOZCARDS ozone data record (with Ray Wang et al.).
- This is ongoing and somewhat preliminary work.
Future work: use reprocessed sonde data (see Thompson et al. and Witte et al. posters), more study of trends, fits, error bars, sonde representativeness, etc...